1.4 Solutions and Concentrations

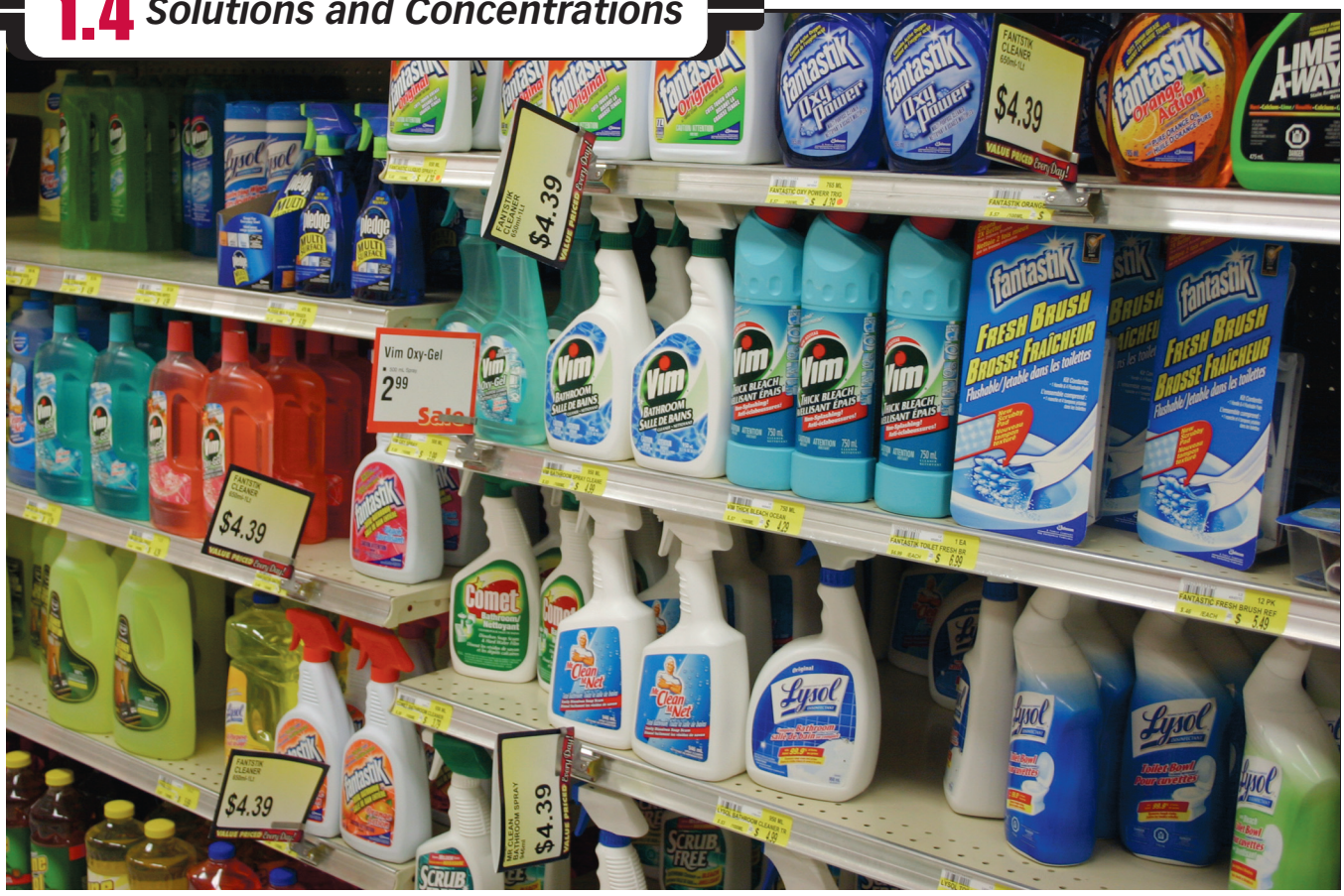


Figure A1.13: Most household cleaners are sold in solution form.

As a consumer, you use many products that are sold in the form of solute dissolved in a solvent—a solution. Beverages, medicines, household cleaners, and hair-care products are all examples of commercial solutions people use on a regular basis. In each case, manufacturers make sure that the ratio of solute to solvent is safe and appropriate for the application. Changing this ratio can dramatically change the properties of the solution.

DID YOU KNOW?

A concentrated solution of acetic acid would hurt you if you drank it. Yet, most people commonly use vinegar—a 5% solution of acetic acid—as an ingredient in their cooking. To keep consumers safe, there are regulations about the proper labelling of products. The ratio of solute to solvent is often noted on the product's label.

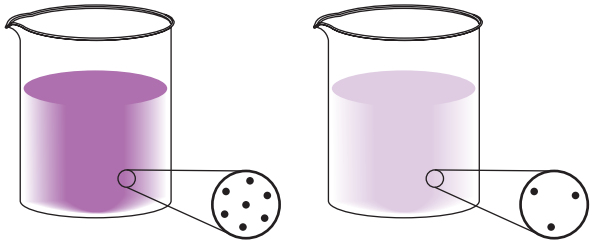
In some cases, the solute that may be part of the product is an unintended ingredient. Polychlorinated biphenyls (PCBs) are pollutants that can be present in water. They may also be found in fish living in water polluted with PCBs. The maximum concentration allowed by Canada's health guidelines regarding the level of PCBs in fish that are harvested to be eaten is 2 parts per million (ppm). This guideline is to ensure that the fish you eat will not harm you.

Figure A1.14: Canada has strict guidelines regarding the levels of PCBs present in fish sold for human consumption.

All of these examples relate to the amounts of a certain substance present in a solution. Whether it is the amount of PCB in fish or the amount of acetic acid in vinegar, the ratio of solute to solution is described as a solution's **concentration**. A solution with more solute in it than a solution of the same volume is said to be more concentrated. A solution containing a large amount of solute per given volume is called a **concentrated solution**. A solution containing a small amount of solute per given volume is called a **dilute solution**.

- concentration: the ratio of the quantity of solute to the quantity of solution
- concentrated solution: a solution containing a high ratio of solute to solution
- dilute solution: a solution containing a low ratio of solute to solution

Concentrated Solutions and Dilute Solutions



A concentrated solution has a high ratio of solute to solution.

A dilute solution has a low ratio of solute to solution.

The concept of concentration is something you encounter every day. Whether you are buying juice or cleaning products or looking at government guidelines for water quality, you are dealing with concentrations. Understanding concentration will help you answer questions like the following:

- How much of the solute is in the product you are buying?
- What are the safe or acceptable limits for certain chemicals in food or drinking water?
- Are there safety concerns associated with products that have higher solute concentrations?
- Can you save money by buying concentrated solutions and diluting them yourself?

These are a few of the questions you will be exploring in this lesson and the next. Not only will you find that understanding concentration gives you a greater knowledge of the information listed on the products you buy, but it will also give you a better understanding of how to interpret and analyze this information.

Practice

One of the "hidden costs" included in the price of most consumer products is shipping—the cost of transporting the goods from the factory or warehouse to the store. If the consumer product is in the form of an aqueous solution, it is frequently shipped in a concentrated form to reduce the mass of the product. Every litre of water that does not have to be shipped reduces the load by 1 kg, helping keep transportation costs low.

25. Soft drinks served at many restaurants are dispensed from a "fountain." In this process, the concentrated form of the soft drink is taken from a pressurized canister and mixed with carbonated water. Explain the advantage of using a concentrated form of soft drink stored in a canister.
26. A fertilizer for flowers is sold as a dry, granular powder that must be mixed with water by the gardener before applying it to the flowering plants.
    a. Determine whether the dry, granular powder is the solute or the solvent of the liquid fertilizer solution.
    b. A 0.500-kg package of this dry powder is capable of making 189 L of liquid fertilizer solution. By approximately what factor would the shipping costs increase if the fertilizer was sold to consumers as a ready-to-use liquid?
    c. List some disadvantages of selling a dry powder that requires the gardener to mix the liquid fertilizer solution.

Observing the Effects of Reduced Concentrations

In the next investigation, "Repeated Dilutions," you will have an opportunity to observe the effects of concentration on a chemical reaction. Although the observations of this investigation focus on colour changes, the solution has its concentration reduced as measured by the number of moles per litre. The meaning of this unit will be explored fully in Lesson 1.5. For this investigation, you only need to know that a solution with a concentration of 4.00 mol/L has twice the concentration as a solution with 2.00 mol/L.

Investigation

Repeated Dilutions

Purpose

You will observe the effects of concentration on a chemical reaction.

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Materials

- 100-mL graduated cylinder
- 9, 100-mL beakers
- distilled water
- phenolphthalein solution in a bottle with an eyedropper
- 100 mL of 1.00-mol/L sodium hydroxide solution NaOH(aq)
- masking tape
- felt-tipped pen
- stirring rod

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Measure 50 mL of distilled water using the graduated cylinder, and pour it into a beaker. Label the beaker "Distilled Water."

step 2: Measure 100 mL of sodium hydroxide solution using the graduated cylinder. Pour this solution into another beaker. Label the beaker "1."

step 3: Pour 50 mL of the solution in beaker 1 into the graduated cylinder. Carefully add 50 mL of water so the graduated cylinder now has 100 mL of solution. Pour this diluted solution into another beaker, labelling it as beaker "2." Note that the solution in beaker 2 has only half the concentration of beaker 1 because the amount of solvent has been doubled. In other words, the concentration in beaker 2 is 50% of the concentration in beaker 1.

step 4: Repeat step 3 by halving the volume of the solution in beaker 2 and creating a new solution in beaker 3. Repeat this process by using the solution in beaker 3 to create a more dilute solution in beaker 4 and so on until you have eight beakers with successively more dilute concentrations. Each beaker will end up with a solution that is half the concentration of the previous beaker. All of the beakers will have 50 mL of solution except for the last beaker, which will have 100 mL.

step 5: Carefully add two drops of phenolphthalein solution to beakers 1 through 8 and to the beaker with the distilled water. Observe the effect of the phenolphathalein on the solution in each beaker. Stir the liquid using a clean stirring rod, rinsing it off between each beaker.

Analysis

1. Copy and complete the following table.

Beaker	Concentration of NaOH(aq) Relative to Beaker 1
1	100
2	50
3	
4	
5	
6	
7	
8	

2. Identify the manipulated variable and the responding variable.
3. State the process that you used to create the solutions in beakers 2 through 8.

Qualitative Properties of Solutions

You know the difference between concentrated juice and dilute juice because you can taste the difference. You should also see a difference in the colour and consistency. You can get a lot of information about a substance simply by observing its physical properties, like colour, taste, and odour. These are the **qualitative properties of a solution**.

Figure A1.16: The solution on the left has a higher concentration than the solution on the right.

qualitative property of a solution: a basic attribute of a solution you can observe with one or more of the five senses

Qualitative properties include a description of a solution's

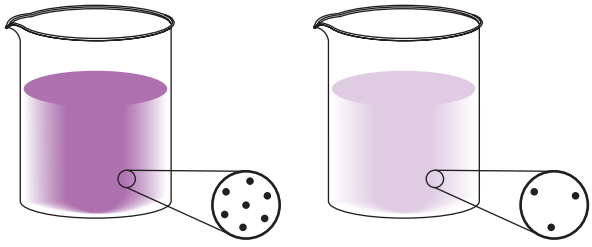
- colour
- colour intensity
- taste
- odour
- transparency

CAUTION!

Never taste or inhale any solution prepared in a laboratory.

Because the solute provides each solution with a new set of properties, qualitative tests can be used to detect the presence and, in some cases, identify the solute present in a solution. Often, the difference in the qualitative observations between concentrated and dilute solutions is directly related to the number of particles of solute dissolved within the solution. As shown in the "Repeated Dilutions" investigation, the greater the number of particles in the solution, the greater the specific effect. The beaker that had the lowest concentration of sodium hydroxide had the fewest particles to react with the drops of phenolphthalein to produce a colour change. A highly concentrated solution had a deeper colour because it contained more solute particles (sodium hydroxide) to react with the phenolphthalein.

Qualitative Characteristics of Solutions



A concentrated solution has many dissolved particles, resulting in a higher conductivity and in a more intense colour, taste, and scent.

A dilute solution has fewer dissolved particles, resulting in a weaker conductivity and a less intense colour, taste, and scent.

4. How many times did you dilute the sodium hydroxide solution before you reached a point where the diluted solution no longer reacted with the phenolphthalein? Is it possible to dilute the solution to the point where it will have no sodium hydroxide left?
5. Imagine that the fluid you were diluting was sewage instead of sodium hydroxide. You repeated this experiment and produced eight beakers of sewage in decreasing concentrations.
   a. Would you feel comfortable drinking from beaker 8? Give a reason for your answer.
   b. List some substances that might affect the quality of the water.
   c. Use the Internet or other resources to obtain a copy of the drinking water standards for your local area or the Guidelines for Canadian Drinking Water Quality to determine what kinds of tests are performed on drinking water to ensure its safety. Are tests for the substances you listed in question 5.b. included in the standards?

Figure A1.15: Sewage must be processed thoroughly before returning to the environment.

It is not always easy, however, to use qualitative properties to compare the concentrations of solutions. This is especially the case for colourless solutions. How could you determine which of the following solutions had the higher concentration?

Figure A1.17: Sometimes it is difficult to tell which solution has a higher concentration just by looking.

As you explored earlier, one method to accomplish this task would be to compare how the two different solutions conduct electricity. It is possible to place two electrodes into a solution and measure how easily an electrical current can pass through the solution from one electrode to another. Solutions with higher concentrations are more effective than dilute solutions at passing the current through the solution.

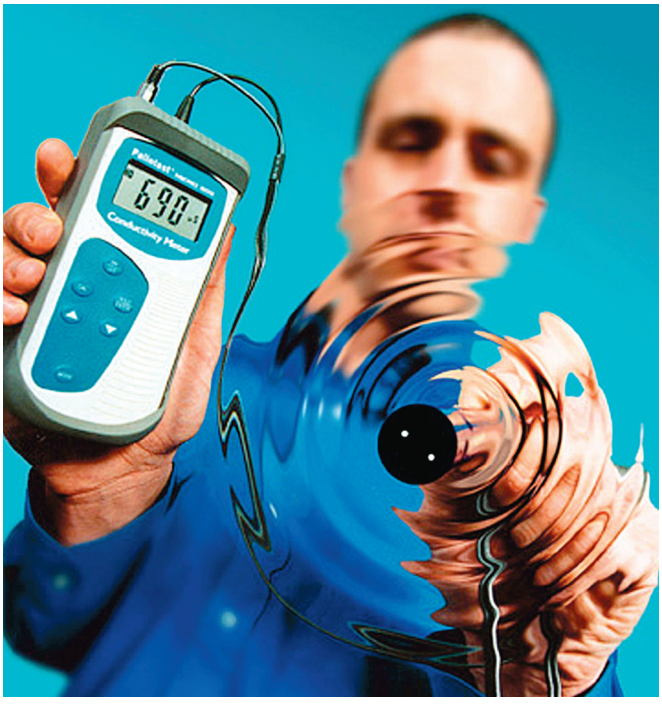
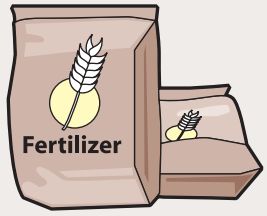


Figure A1.18: A conductivity meter provides numerical data for comparing solutions.

Another method to determine the relative concentrations of two solutions is to look at chemical characteristics, such as how readily each solution reacts.

Practice

27. Many fertilizers sold to gardeners have a non-staining dye to the ingredients. This dye has no beneficial effects on the plants, but it serves many purposes for the gardeners.
    a. Suppose two gardeners each read the instructions on two bags of identical fertilizer and worked independently to prepare their solutions. Each gardener produced a solution of liquid fertilizer in identical 20-L pails. Although both solutions were blue, one has a much more intense blue colour than the other. Identify which pail has the more concentrated solution and suggest what these two gardeners should do next.
    b. Many liquid fertilizers can be dispensed by a hose. Why is the presence of the dye in the fertilizer regarded by some gardeners as a useful safeguard?

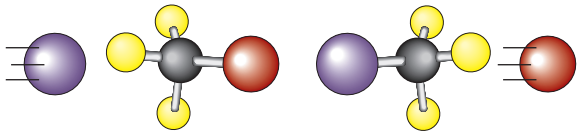


DID YOU KNOW?

All chemical reactions involve collisions between atoms, ions, and molecules. This idea is explained by the **collision-reaction theory**. This theory states that a chemical reaction will occur if the particles collide with a certain minimum energy and if they collide with a certain orientation. The rearrangement of particles that occurs after the collision is the chemical reaction.

collision-reaction theory: a theory stating that chemical reactions involve the collision and rearrangement of particles

Example of Collision Theory



$I^-(g) + CH_3Br(g) \rightarrow CH_3I(g) + Br^-(g)$

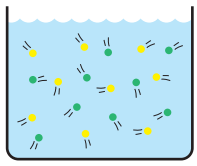
This reaction only occurs if the iodide ion, $I^-(g)$, collides with enough energy, travelling from the direction shown.

Concentration Affects the Speed of Chemical Reactions

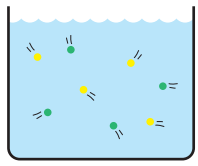
A solution having a greater concentration of solute to solution reacts faster than a more dilute solution. This occurs for the following reasons:

- A chemical reaction is a result of collisions between particles.
- A concentrated solution has more particles of solute available for possible collisions than a dilute solution.
- The probability of collisions increases as the number of solute particles within a system increases.

Reactions of Concentrated Versus Dilute Solutions



Reactions with concentrated solutions occur more quickly because you have a greater number of collisions.



Reactions with dilute solutions occur at a slower rate because collisions are a little less probable.

1.4 Summary

Concentration is a description of the amount of solute dissolved within a solvent to form a solution. A concentrated solution has more solute particles dissolved in the solution than a dilute solution. The amount of solute in a solution can affect the qualitative characteristics of that solution, such as the intensity of colour and reactivity with other substances.

Concentrated solutions and dilute solutions have similar physical characteristics; but due to the number of particles in a concentrated solution, there tends to be an increased intensity of physical and chemical properties. These properties include greater colour intensity and an increased rate of chemical reactions.

Figure A1.19: Using only one of the five senses, it is very difficult to determine which solution is more concentrated.

1.4 Questions

Knowledge

1. Define the following terms.

a. concentration
b. concentrated solution
c. dilute solution
d. qualitative properties
e. collision-reaction theory

2. Describe how the qualitative characteristics of concentrated solutions compare with those of dilute solutions.

3. Explain why a chemical reaction appears to occur faster using a more concentrated solution versus a dilute solution.

Applying Concepts

4. A person accidentally swallows a poisonous compound. You immediately call the local poison control centre. They tell you that the person should drink at least three glasses of water and then go to the hospital. State a reason for the advice given.

5. State two situations when dilute solutions are used and two situations when concentrated solutions are used.

6. Explain why you must be much more aware of safety procedures when working with concentrated solutions than with dilute solutions.

7. Suggest appropriate safety procedures for shipping concentrated solutions by rail cars.